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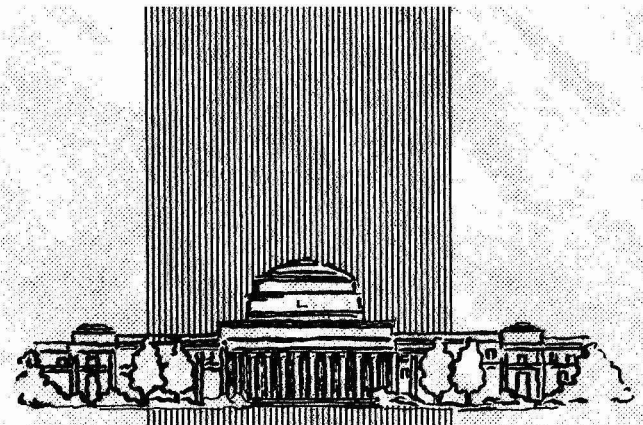

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

STUDIES OF HUMAN DYNAMIC SPACE ORIENTATION USING TECHNIQUES OF CONTROL THEORY

Principal Investigators: L. R. Young
Y. T. Li

June 1970

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Status Report on
NASA Grant NGL 22-009-025

MAN-VEHICLE LABORATORY
CENTER FOR SPACE RESEARCH
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE, MASSACHUSETTS 02139

STUDIES OF HUMAN DYNAMIC SPACE ORIENTATION USING TECHNIQUES OF CONTROL THEORY

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for the period July 1969 - June 1970

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Principal Investigators: Professor L. R. Young
Professor Y. T. Li

Massachusetts Institute of Technology
Department of Aeronautics and Astronautics
Man-Vehicle Laboratory
Center for Space Research

STUDIES OF HUMAN DYNAMIC SPACE ORIENTATION USING TECHNIQUES OF CONTROL THEORY

ABSTRACT

The Man-Vehicle Laboratory expanded its interests and staff in the academic year 1969-1970 to include a number of areas allied with but not directly in the area of dynamic space orientation. In particular, we have had expanded interest in research in vehicle display systems. The following list of laboratory project titles shows the breadth of our work. Those marked with an asterisk were supported all or in part by Grant NGL 22-009-025.

A. Displays
   1. Perspective glideslope display and evaluation*
   2. VTOL "Bottom Window Display"*
   3. VTOL display simulation*
   4. Elements of pictorial displays*
   5. Pilot warning indicator displays
   6. Auditory displays*

B. Manual Control
   1. Adaptive manual control*
   2. Postural control models
   3. Neuromuscular control system
   4. Extravehicular activity attitude control*

C. Visual Systems
   1. Pursuit eye movements*
   2. Eye movements and apparent motion*
   3. Influence of target motion on small saccadic eye movements
   4. Visual patterns and cognition*

D. Vestibular Functions
   1. Unified vestibular models
   2. Adaptation to sustained stimuli
   3. Semicircular canal thresholds and simulator requirements*
   4. Galvanic stimulation

E. Cybernetics
   1. Rapid on-line identification of dynamic system failures*
   2. Self-organizing control systems and applications to the human operator*
   3. Symmetrical properties and learning theories

F. Computer Development and Laboratory Facilities
   1. Hybrid computer operating system*
   2. Integration of Link GAT-1 in the laboratory

G. Medical Applications
   1. Glaucoma research
   2. Clinical applications of synchronized photography and hybrid computer displays

H. Life Support in Unusual Environments
   1. Atmosphere storage and control
   2. Water recovery
   3. Contaminant monitoring
   4. EVA attitude control
   5. Temperature control
   6. Space power systems

MAN-VEHICLE LABORATORY

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I. DISPLAYS

The area of pilot display research, principally for aircraft applications, has increasingly occupied the Man-Vehicle Laboratory. During the academic year 1969-70 six graduate students and all of the laboratory's faculty and staff members were associated to some extent with advanced display generation, making use of our aircraft simulator facilities and the Adage AGT-30 Computer Graphics machine. Four of the projects are associated with development and evaluation of pictorial or skeleton pictorial integrated displays for aircraft. They emphasize terminal area operations. They have usually been tested for VTOL, because of the severity of the stability problem in the unstabilized aircraft and the challenges of developing displays suitable for steep approaches in poor visibility.

1.1 Perspective Glideslope Display and Evaluation

A perspective glideslope display for VTOL landing operations was conceived, simulated and evaluated in our laboratory as the Ph.D. thesis of Noel Van Houtte. The display is of the "highway in the sky" type with all necessary attitude and position information available from the skeleton picture. In practice only ground speed had to be added to this picture. Figures 1 and 2 represent the display as seen from various positions along the glideslope. The display evaluation was quite encouraging. Further development on the current hybrid computer is limited by hardware, and we are considering implementation of the display on the AGT-30 with a remote monitor and our moving base simulator.

The complete thesis is being made available as a laboratory report and the extensive body of PDP-8 programs necessary for its implementation will be furnished to qualified users. The abstract of Dr. Van Houtte's thesis appears below.

Display Instrumentation for V/STOL Aircraft in Landing

by

Noel A. J. Van Houtte
Sc.D. Thesis, May, 1970

Abstract

This thesis concentrates on the instrumentation of aircraft, facing the problem of steep angle approaches or landing in zero-zero visibility.

A V/STOL aircraft (of the tilt-engine type) has been simulated, using the non-linearized form of the equations of motion, and has been flown from cruise altitude to touchdown with severe wind disturbances, descending along glideslopes of 4.47° , 8.87° , and 17.3°.

Three kinds of instrumentation have been used: a conventional set of cockpit-like instruments, the same set augmented by means of a flight-path profile display, and a contact analog perspective glideslope indicating system.

A general display program has been written, to display a skeleton scenery, consisting of lines connecting characteristic points. The lines in this application are the runway boundaries, the glideslope lines and several distance indicating poles. The display is generated on a large screen cathode ray tube, using an analog line drawing scheme. The picture changes dynamically and is updated by a digital machine sixteen times per second, using the translational and rotational rates of change, resulting from the motion of the observer.

The piloting task consisted of staying level flight until intercept of the glideslope, then in tracking the glideslope to hover and in landing the aircraft with minimum impact velocity and maximum accuracy. The task was quite difficult, because of the lack of stability augmentation.

Three classes of pilots of different experience have been examined and different control techniques have been observed with the perspective glideslope indicating system.

The value of the perspective glideslope indicating system has been shown in:

1) the ease of performing coordinated maneuvers, allowing large but quite precise changes of the flight variables,
2) the consistency of touchdowns,
3) the accuracy of tracking the glideslope, with dead beat response,

4) the learning curve, and
5) the effectiveness of the representation of the integrated real world outside picture.

1.2 VTOL "Bottom Window Display"

The original development of a VTOL "bottom window display" for integrated horizontal and vertical situation information in a VTOL was completed by Major Gordon Kemp (CAF) as his thesis for the degree of Engineer in Aeronautics and Astronautics in September, 1969. The essential elements of this display were discussed in a previous status report and its current status is discussed below in Section 1.3. The abstract of Major Kemp's thesis is given below.

A VTOL Prediction Display

by

Gordon George Kemp

Engineer of Aeronautics and Astronautics
Thesis, September, 1969

Abstract

Prediction displays allow human operators to control difficult plants more precisely than conventional displays, and with decreased learning times. This thesis applies the principles of prediction display to the VTOL control problem. A typical VTOL is simulated in six (6) degrees of freedom on a digital computer. The computer is linked to a graphics terminal which is used to draw the proposed prediction display.

The display simulated is a "plan-view" display on which pitch and roll information is portrayed as projections of the aircraft Y-Z and X-Z planes respectively, onto the ground. Prediction information is displayed in attitude and position.

Preliminary results show prediction to be useful. Further testing is required to quantify these results.

1.3 VTOL Display Simulation

In order to evaluate pilot performance with Kemp's pre-

dictive display, Robert Anderson simulated a set of conventional primary instruments on the CRT, modeled after the Collins system. The Doak VZ-4 simulation and both displays are generated on an AGT-30 Adage computer. Both the dynamics and display are updated 30 times per second.

The flight task required of our pilots is a 7 and 1/2° (1/8 radian) glideslope approach and landing from 1500 feet altitude and 3 miles out, with an initial airspeed of 140 knots.

The pilots used for the evaluation have instrument ratings and one has considerable helicopter experience.

The original simulation had a number of unacceptable characteristics. Although our interest was in having a bare vehicle with no stability augmentation system, the literature indicates that the Doak VZ-4 has an auxiliary turbine in the tail with directional vanes coupled to the elevator and rudder to supply the necessary control moments at low air speeds; and these terms did not appear in the original simulation. The pilots also complained that the roll damping was unreasonably weak at all speeds so this term was doubled, giving much more favorable handling characteristics. For the rudder we are adding a small dead zone and spring centering.

The pilots are still in the training stage, preparing for a series of data runs. Hence only a few observations can be made at this time:

1. The conventional instrument display is readily accepted by the pilots and they seem quite comfortable with it until reaching the final transition to hover and touchdown.

2. During early training, the integrated display produces control actions opposite to those desired.

3. As training continues the pilots claim to build an internal model of their flight condition and thus say they are flying more by intuition than in direct response to displayed information - this is with the integrated display.

A cost function based upon a smooth flight within acceptable approach bounds will be used to evaluate the performance of the pilots with the two display systems. A side task involving proper identification and extinguishing of a right or left indicator at the bottom of the CRT has been implemented. The side task is coupled to the performance criteria so that it no longer appears on the screen if performance becomes poor. With a time varying system such as we have, the interpretation of the results of the side task is not immediately clear, hence data will be taken both with and without the pilot responding to the side task.

The "bottom window display" is shown in Figures 3 and 4, and the simulated conventional system in Figures 5 and 6.

1.4 Elements of Pictorial Displays

Fundamental to all developments of new display concepts lurks the illusive notion of a "theory of display". Such a theory would predict information transfer, performance, and acceptability of display concepts and allow for conventional engineering synthesis of displays in its current practice. As an attempt to begin work in this area, Eric Chang is working on a master's degree thesis on evaluation of elements in a contact analog display.

The area of concentration of this investigation in contact analog displays is in display evaluation, and should not be confused with display design or the establishment of display requirements.

The proper viewpoint, then, for display evaluation should look at the effect of the displays on the psycho-physical aspects of pilot performance in relation to given tasks. By some figure of merit derived from performance, the comparison of [illegible]ays is made possible.

Experiments were conducted to try to answer the following basic questions:

1. What is a good criterion for comparing the relative merit of one display to another? Once this has been settled, another question is posed.

2. Suppose to a bare format more and more elements are successively added. How much does each added element contribute to the pilot's performance of some task? At what point do additional elements become cluttered and actually hinder performance?

3. Is there a logical procedure that determines an "optimal" set and ordering of elements?

Specifically, the phases of the experimental evolution are:

a) assignment of tasks

b) formulation of a basic display format

c) building successive display configurations by adding different types of elements

d) testing subjects on the display configurations

e) recording many performance variables

f) determining a criterion for display comparison from these variables

g) comparing the display configurations and thus determining the contribution of the elements.

The display is studied with the goals of examining the information content in the display configurations and the contribution of individual elements to performance.

The subjects are studied with their learning curve and task accuracy in mind. These are in turn used to derive the display evaluation.

The experimental approach has been to employ a fixed-base simulation by generating the displays through a computer driven CRT screen. A control stick was mounted to a chair in front of the screen and the control signals fed into the computer.

The display format was chosen to represent the landing phase of a theoretical fixed-wing aircraft with simple first order dynamics.

To make results more generally applicable, the display format base for the addition of elements was kept as universal as possible and only elements consistent to the real visual world were included. No digital read-outs, pointers, or excessive symbols were allowed to obscure the pictorial quality of the displays.

The display parameters varied were the separate elements of the format and the display initial conditions. The effects of display gain, intensity, and size were not investigated, since standard evaluation techniques in these areas have been established.

To date, the testing of five subjects for each of five display configurations is in progress. Not enough data has been collected yet to yield some conclusive results. The testing is expected to be completed in another week and data reduction started.

1.5 PWI Displays

A new research project was initiated this year in the area of cockpit displays for aircraft collision warning systems. Such displays aid the pilot in his task of detecting other aircraft and provide a greater margin of safety. This project, sponsored by NASA/ERC (NGR 22-009-444) is being supervised by Professor Curry.

The first experiment was a student laboratory project done by Charles Burr. Burr set out to examine the feasibility of a stereophonic audio warning, i.e., a single apparent sound source from two speakers. Such a device could be made to have the warning sound (buzzer) appear to come from the direction of the target. Burr found that the repeatibility of the subject's ability to localize the apparent source was probably not accurate enough to use without supplemental visual displays.

Basil Smith designed an experiment to examine the effect of heads-up display resolution on the time it takes a subject to detect a target. Preliminary results indicate that there is an intermediate sector size which will provide the shortest mean time to detection as had been hypothesized. Data is currently being taken to determine the effects of different parameters such

as background intensity, target contrast, etc.

Roger Marian, in a laboratory project, is modifying Smith's experimental setup to evaluate audio displays. The adaptation is nearly complete, and initial runs will compare a simple warning buzzer, the conventional advisories ("traffic at 2 o'clock"), and other vocabularies.

John Hatfield has converted the Link GAT-1 trainer to a moving base simulator for target detection studies. This simulator has the display dynamically coupled to the target; different sectors of the display are actuated by the relative motion of the target induced by simulator movement. This simulator will provide the capability to evaluate all displays, both audio and visual. Important parameters to be measured are the ability to detect targets and to simultaneously maintain aircraft attitude, heading, airspeed, and altitude.

1.6 Auditory Displays

It has frequently been suggested that auditory cues can be used to supplement or replace some elements of visual display for flying and other complex multi-axis control tasks. The use of a second sensory modality for control should add to total information processing rate until such rate is saturated. P. B. Mirchandani conducted a series of experiments in this area. The present study was concerned with the evaluation of combined auditory-visual display techniques in a dual axis compensatory control situation. In the experiments, the operators were presented with two concurrent compensatory tracking tasks. The primary task was the control of a double integral plant. The

secondary task was the control of a velocity type control system, using a separate display. Both plants were given a random input disturbance, and the task of the operator was to keep both the plants at null position.

The object of the experiment was to compare the performance for both plants, with and without an audio cue supplementing the secondary task.

In the preliminary experiments three types of auditory systems were used: frequency regulating, volume regulating, and a combined frequency-volume regulating system. The last type was superior. The null position corresponded to a reference frequency of 1000 Hz. A positive error increased the volume as well as the frequency. A negative error increased the volume but decreased the frequency. The reference volume was set a little above threshold such that this gave a maximum volume sensitivity.

Two types of performance measures were obtained. One was the integral of error squared (ISE). The other performance was the describing function of the operator. Analysis shows that ISE on the $1/s^2$ plant does not change significantly. However, there is a definite improvement (significance of .05) in the performance on the 1/s plant with the combined audio cues. The describing functions also seem to indicate a change only in the 1/s plant. It appears that the gain of the human operator is increased when the display is supplemented with auditory cues.

The results of this study indicated that the performance of a multi-axis control system, requiring considerable training, would probably be improved when one or more of the tasks are sup-

plemented with an auditory display. These findings could have significant effect in manual control systems. It is quite conceivable that supplementary audio display systems in existing systems, such as airplanes (especially helicopters and VTOLS), in space maneuvers, in real time command and control systems, in monitoring systems, and in situations of dark environment, could make the systems more efficient.

II. MANUAL CONTROL

2.1 Adaptive Manual Control

A survey of this subject, entitled "On Adaptive Manual Control," by L. R. Young, was delivered as an invited paper at the IEEE-ERS International Symposium on Man-Machine Systems, Cambridge, England, September, 1969. The paper appeared in Ergonomics, September, 1969, and was reprinted in the IEEE Transactions on Man-Machine Systems, December, 1969. Its abstract was given in a previous status report. Research in the basic mechanism of changes in the human control characteristics with learning or presentation of new control element dynamics has continued. In particular, we are investigating the possibilities of application of our fast on-line identification schemes to tracking changes in human operator characteristics.

2.2 Postural Control Models

The doctoral dissertation of Lewis M. Nashner on human postural reflexes was completed in May, 1970. This represented a major experimental program to develop a model showing how humans use combinations of visual, vestibular, and kinesthetic cues for stabilizing themselves in the erect posture. The thesis was supported principally under NASA Grant NGR 22-009-156 and is summarized more fully in status reports under that grant. The possible applications of this research to manual control are chiefly in the area of posture controlled vehicles including "flying carpet", "jet shoes", "balance platform", and other at-

titude and propulsion control systems. The abstract of Dr. Nashner's thesis appears below.

Sensory Feedback
In Human Posture Control

by

Lewis Michael Nashner
Sc.D. Thesis, May, 1970

Abstract

Current models for physiological components and a series of experiments on human subjects form the basis for a multiloop control model which describes how a human uses multiple feedback sensors to control his orientation. Particular emphasis is placed on defining functional interfaces between the feedback sensors and postural responses. Because of the inherent complexities within the posture control system, analysis is simplified by considering only control of forward and backward rotational motions about the ankle joints during quiet standing tasks.

The research effort is divided into three segments. First, a general posture control model is assembled given current models for motor and sensory components. This general model forms the basis for a series of experiments with human subjects using a specially designed two-degree-of-freedom simulator. Finally, experimental observations are combined with the general model, developing specific models which predict the observed postural responses.

During quiet standing on a rigid surface ankle reflex gain is about one third that necessary for postural stability. Ankle reflexes, however, are adequate to fully stabilize very small deflections due to the presence of "stiction" forces acting between fibers in intra- and extra-fusal muscle fibers. Quiet standing is punctuated by frequent transients during which the subject "breaks out" of static reflex stability and begins to diverge. A kinesthetic threshold is reached, commanding a transient multiplicative increase in reflex gain proportional to disturbance amplitude. A static sense, either vision or utricle otolith is necessary to correct slow drift of this reflex/kinesthetic control loop.

When reflex and visual feedback are removed, the vestibular sensors are able to fully stabilize posture. The utricle otoliths and semicircular canals act as frequency selective feedback sensors. The canals detect sway divergence and initiate corrective postural responses. The utricle otoliths provide a static vertical reference to stabilize slow drift of the canal control loop. Otolith cues are shown to be ambiguous at higher frequencies because of interactions between linear motion and gravitational stimuli.

Control strategy is observed in one subject with complete loss of vestibular function but with normal motor control. When eyes are open, the subject shows reflex/kinesthetic control strategy which is very nearly normal. The subject is also able to stand with eyes closed; however, this required great effort. Tests show eyes closed control strategy to be radically different. Extensor reflex gains were increased six-fold, allocating almost complete control of function to reflex "rigidity".

2.3 Neuromuscular Control System

Mr. J. H. J. Allum has been working on a new model of the muscle spindle to gain a fuller understanding of the control characteristics of the human neuromuscular system in tracking tasks. It is intended to test the model's sensitivity to parameters given in the literature and to a series of tracking experiments for the critical task $K/(S-\lambda)$. In addition to the tracking of pseudo-random signals (spectral lines in the frequency domain) the control stick will be subject to a random signal (white noise with aforementioned spectral lines "notched" out) and to step inputs applied when the subject's arm has a certain position (left or right of a central position [null]) and velocity (to the left or right).

The preliminary aspects of the tracking experiments have been completed in the last twelve months. This work, which evolved into three areas, is now 95% complete.

1. Design and construction of an arm manipulator incorporating electric torque motor drive, force and position sensors.

2. Design of the electric torque motor non-linear compensation to enable the torque motor to act as a position or torque transducer.

3. Data processing and analysis design.

Construction of the arm manipulator is now complete. The torque motor has been tested and operated with the equipment as to design specification.

The data processing design is now in progress. The design is a vehicle towards the experiment's objectives. The objectives are:

1. Determine the criteria by which control is allocated among the levels of neuromuscular control under various tracking conditions.

2. Develop a method to distinguish higher center responses and determine the logic of these responses.

3. Investigate the location of remnant response sources.

2.4 Extravehicular Activity Attitude Control

A variety of proposed techniques for involving the astronaut in direct or indirect control of his attitude position during "space walks" or repair operations in the weightless condition was reviewed and evaluated in a report by Mr. L. Von Renner, conducted under grant NGR 22-009-312. As an outgrowth of this research, Mr. Von Renner explored the possibilities of using direct myoelectric control for EVA attitude regulation in a manner somewhat analogous to the electromyographically controlled prostheses recently developed. In an attempt to free the arms and legs from control tasks and to use the human visual and vestibular sensory mechanisms as the primary space stabilization references, Von Renner pursued the notion of "head tracking" in which the body rates are commanded by head position. Sets of

muscles involved in head motion were isolated for orthogonal control of pitch roll and yaw rates and such control demonstrated in the laboratory in our moving-base simulator. The abstract of Mr. Von Renner's master's thesis follows.

Extravehicular Attitude Control By Use of Head Motions

by

Lonnie Charles Von Renner
S.M. Thesis, May, 1970

Abstract

On the basis of a survey conducted on existing techniques for astronaut extravehicular attitude control in space, experiments were performed to determine the usefulness of bioelectric currents generated in muscle tissue as a control signal source.

Muscle sites were identified on the neck and bio-currents (electromyographic signals or EMG's) were detected using surface electrodes. Raw signals were generated by turning the head right or left with respect to the body; subsequent conditioning was performed using a hybrid computer. Motion cues (yaw) were provided by a rotating chair which a subject attempted to control by moving his head. Performance levels based upon integrated squared error were compared for two separate plant dynamics between electromyographic and conventional pencil-stick control.

Examination of the data revealed that control of yaw attitude using EMG's was a practical means of providing hands-off control. However, EMG performance was in all cases poorer than equivalent tests conducted using a stick. This probably resulted from the large deadband ($\pm 45°$ normally) which existed in the physical angle of turn required of the head to produce a measurable signal. Recommendations are made for describing function analysis of the data and the investigation of other, mechanical methods for using head position as a control signal source.

III. VISUAL SYSTEMS

3.1 Pursuit Eye Movements

Since our earlier work on models for eye movements, a number of valuable related experiments have been performed at M.I.T. and elsewhere. Consideration of this additional data led to numerous detailed revisions resulting in our stochastic hybrid eye movement model published in 1968. In further considering some of the more general problems associated with modelling eye movements, including the important non-linear and adaptive characteristics thus far insufficiently explored, L. Young developed a number of basic requirements for any "second generation models" of eye movements. These constraints and requirements were put forth in a paper entitled, "Pursuit Eye Tracking Movements," delivered as an invited paper at the Symposium on the Control of Eye Movements, sponsored by the Institute for Visual Sciences, Smith-Kettlewell Research Institute, San Francisco, November 1969. The text will appear as a chapter in the book, The Control of Eye Movements, Bach-y-rita and Collins, ed., Academic Press, New York, 1970. A summary of that contribution appears below.

Pursuit Eye Tracking Movements

by

Laurence R. Young, Sc.D.

Symposium on the Control of Eye Movements
Smith Kettlewell Research Institute, San Francisco, November 1969

A simplistic view of the human eye tracking system recognizes two major modes of tracking: rapid saccadic eye movements and smooth pursuit movements, and assigns complementary functions to

them. The saccadic eye movement system supposedly acts to maintain the image of the object of interest on the fovea by a sequence of discrete high velocity jumps. The smooth pursuit system has been assigned the role of stabilization of retinal images, or more particularly matching the angular velocity of the eye to the velocity of the object. This view has led to the development of models by several groups, including the author and his colleagues, which treat the saccadic system as a discrete position servomechanism and the pursuit system as a velocity servomechanism. These models have been useful in predicting the response of the eye movement system to a variety of target patterns in a general manner. They have further stimulated experiments which show their shortcomings in detail in a number of ways. This paper deals not with models but with features of the pursuit eye movement system which are known at present, and especially with those characteristics which are still unknown. It will be seen that the pursuit system is not a simple, linear, velocity servo based on retinal error velocity.

3.2 Eye Movements and Apparent Motion

The primal object of an investigation by Syozo Yasui is to study the eye movement control mechanism in visual tracking tasks in relation to subjective visual perception. Targets in illusory motion, caused by the vestibular and optokinetic stimulation are of particular interest.

Recent experimental evidence in the oculomotor control field supports the notion that the eye velocity commands are generated based on the target velocity relative to the subject (egocentric velocity) and not on the velocity relative to the retina.

However, no egocentric velocity of the object is directly available to the brain. Such an open-loop motion may well lead one to the realm of perceptual psychology, presuming the involvement of the Helmholtz cancellation theory in recreating the egocentric velocity by means of subtracting the oculomotor command signal from the retinal velocity. This recreated velocity is supposed to be a subjective one which can differ from the objective one to a considerable extent, giving rise to what we call illusions.

The motor theory of egocentric localization, which offers a coherent explanation for various visual illusions, may be stated in the present context such that retinal velocity is compensated only for voluntary commands and not for involuntary ones. In the presence of an involuntary oculomoter command, this imperfection results in an illusory egocentric velocity sensation.

We currently postulate that this subjective velocity in turn affects the eye tracking command. An engineering model accounting for the above aspects has been proposed. Existing models as to the eye tracking servo and vestibular nystagmus have been adopted in this framework. The visual target and vestibular stimulation (angular acceleration of the head) or optokinetic stimulation (moving vertical stripes in visual background) are two inputs to the system, whereas the eye movement and subjective visual perception about the target are outputs.

The present hypothetical model also assumes that the subjective egocentric position of the target is altered directly by apparent change of the subjective "straight ahead." Thus, the subjective egocentric velocity and position are not necessarily consistent in the Euclidian sense, accounting for the paradoxical perception about the target's motion in the oculogyral illusion, for instance.

It is hoped to establish a mathematical dynamic model regarding a subjective perception as response to the two inputs by deduction from appropriate psychophysical experiments. The subjective straight ahead versus vestibular input relation, for instance, may be obtained by an experiment in which the subject in a rotating chair is asked to press a push button as soon as a target objec-

tively moving randomly across the visual field appears to traverse what he thinks of as his center.

Once this is made, subsequent eye movement data are to be interpreted in attempts to correlate with such a mathematical model of subjective perception. Preliminary fixation tests where the target is stationary have been carried out with both vestibular and optokinetic stimulations. The eye movement results are thus far inconclusive in regard to the plausibility of the present model.

Another simple test was to track a sinusoidally moving target with the optokinetic background. The eye movement trace shows assymetric distortion with respect to direction of motion, indicating some influence of the optokinetic nystagmatic command.

3.3 Influence of Target Motion on Small Saccadic Eye Movements

An undergraduate project by Terry Michael attempted to answer some questions concerning our sample data model for eye tracking movements. Specifically, the project tried to determine whether saccades are position error correctors alone or error velocity correctors. Eye movements of 0.5° or less were studied by having a subject track a moving dot undergoing various movements. Data tended to be consistent but not precise enough to support either model.

3.4 Visual Patterns and Cognition

We have become interested not only in the way the eyes move over a visual scene tracking a simple target, or over a pattern of discrete displays, but also in the way the eye movements are

related to cognition. A first study for our laboratory in this area was performed as the masters thesis of Dilip Mathur. The thesis abstract is given below.

Organization of Information Processes

by

Dilip Kumar Mathur

S.M. Thesis, January, 1970

Abstract

Eye movements of a subject viewing a scene were recorded along with his post-viewing description of it. The scanning record and the verbal description were examined for information about the process whereby the elements of a scene are fixated and organized into a picture. It appears that the eye is guided to the element for fixation by peripheral vision. The distribution of dwell times between the elements obtained from the scanning record matches closely the distribution of attention in the verbal description indicating a strong connection between the two. The elements of the scene are organized by the selection of one element as nucleus and the association of the others to it. The nucleus is characterized by a long dwell time for each look, and a small number of total looks. The associative elements are all similarly processed, although the processing is time-scaled according to their importance. The understanding of the scene is indicated when a logical scanning sequence between the elements is achieved.

IV. VESTIBULAR FUNCTIONS

4.1 Unified Vestibular Models

Our central interest in the vestibular system, its physiology, and its implications for aerospace research continues to occupy a significant portion of the laboratory. Most of the work aimed at clinical applications and the underlying physiological mechanisms of the vestibular system is supported separately under grant NGR 22-009-156. Those studies which are more applications-oriented and deal with the effects of motion cues on pilot performance, disorientation, and motion base simulator requirements are supported under the subject grant. The unified model of vestibular function referred to in a previous status report was published under the title, "The Current Status of Vestibular System Models," by L. R. Young in Automatica, Vol. 5, pp. 369-383, September, 1969. The material was also discussed in invited presentations and seminars at the Joint Automatic Control Conference, Boulder, Colorado, August, 1969, and in the Princeton University Baetjar Colloquium, April, 1970. Our current interest in the unified model is in integration of semicircular canal and otilith information to give unique perception of orientation when both organs are stimulated. We are also concerned with the interaction between visual and vestibular stimuli.

4.2 Adaptation to Sustained Stimuli

The research on the response of subjects to prolonged

rotational stimuli in the horizontal plane led to adoption of separate adaptation time constants for a nystagmus and subjective sensation reported on previously. Additional information from Clark and Stewart further supports such a non-rational parameter quantitative model for semicircular canal adaptation. The abstract of one paper by L. R. Young and C. M. Oman entitled "A Model for Vestibular Adaptation to Horizontal Rotation," was previously reported. The paper appeared in Aerospace Medicine, Vol. 40, No. 10, pp. 1076-1080, October, 1969. A non-mathematical treatment of the subject is given in a paper by L. R. Young and C. M. Oman, entitled "Modelling Adaptation in Human Semicircular Response to Rotation," Transactions, New York Academy of Sciences (in press), the abstract of which appears below.

Modelling Adaptation in Human
Semicircular Response to Rotation

by

Laurence R. Young
Charles M. Oman

Abstract

The mathematical description for human semicircular canal response can be improved by addition of adaptation dynamics in the pathways to subjective and nystagmus response. Adaptation is represented as a shifting reference level based on the recent history of cupula displacement.

4.3 Semicircular Canal Thresholds and Simulator Requirements

One of the persistent conceptual difficulties with the laboratory's model for human response to rotation has been with the repre-

sentation of the threshold to acceleration. A direct, simple threshold in the form of a deadzone to angular acceleration has been ruled out because of the relationship between stimulus angular acceleration and the onset of sensation, as demonstrated by Mulder and others. In his 1965 model, Meiry included a threshold based on deviation of the cupula, although he noted that this representation should not be taken literally. In the 1968 model of Young and Oman, we reinterpreted the threshold to be a deadzone operator acting on the cupula signal after an adaptation operator, with the input having the dimension of angular velocity. While this configuration facilitated correlation with available latency time data, a number of objections have been raised about it. For example, in experiments on secondary nystagmus by Malcolm, Outerbridge, and Jones at McGill, and by Malcolm and Oman at M.I.T. in the summer of 1968, postrotary nystagmus velocity was seen to decay smoothly through zero, with no evidence of threshold.

One of our primary problems in formulating a viable model for threshold is that consistent data is lacking, and is only gradually becoming available. Brant Clark has pointed out that measured thresholds vary from .035 deg/sec^2 to 8.2 deg/sec^2, but that a large amount of the variability in the measurements may in fact be related to differences in the experimenter's definition of threshold, and the modality used to measure it. It is generally conceded that the most reliable estimator of mechanical vestibular threshold may be results from tests of occulogyral illusion, but there is some inconsistency in measured values for this threshold as well.

Several recent research results suggest that modeling canal thresholds may not just be an exercise in determining the adequate acceleration step stimulus. Dohlman has suggested that endolymph may, in fact, have highly non-Newtonian properties, because of the high concentration of the mucopolysaccharide halyuronic acid present in the cupula and in the vicinity of the planum semilunatum surrounding it.

As part of his Doctoral thesis, Oman intends extending the models for vestibular thresholds in both the semicircular canals and the otoliths by conducting experiments aimed at defining the thresholds of mechanical stimulation of these organs. These will involve tests using the most direct behavioral indicators in man, occulogyral and occulogravic illusion, with perhaps some supporting direct physical and neuroelectric measurements, possibly in the frog. He also hopes to determine whether fresh, unfrozen samples of human endolymph exhibit non-Newtonian characteristics, which would implicate "stiction" in the dynamics of both the canals and otoliths. Steer's rolling ball microviscometer is available for preliminary tests, although possibly other methods will have to be found.

We plan to apply the results of this research to the problem of analytical design of motion cues for moving base simulators. This problem is of some practical importance, since indications are that existing techniques of applying washout to motion cues result in considerable overdesign of motion capability in many cases. Accurate descriptions of vestibular thresholds are required to use the laboratory models for vestibular response in an analytic design

procedure, however. Hopefully, experiments showing the relationship between "absolute", postural reflex, nystagmus, and subjective thresholds, with eyes open and closed, with moving and fixed visual fields should define a more viable threshold model.

4.4 Galvanic Stimulation

With the addition of Dr. Alfred Weiss to our laboratory, the interest of possible clinical applications of our vestibular research and possible long-range prosthetic devices has increased. With the advent of vastly improved instrumentation and especially dynamic analysis techniques, a re-examining of galvanic stimulation of the vestibular apparatus seemed appropriate. Dr. Weiss supervised a set of preliminary experiments in this area. J. Tole used the laboratory single-axis chair, and eye movement monitoring techniques, in conjunction with the nystagmus data processing program described below, to develop models for vestibular galvanic stimulation. The preliminary experiments have been completed and are reported in Tole's thesis, the abstract of which is given below.

Galvanic Stimulation and the
Perception of Rotation

by

John R. Tole
S.M. Thesis, June, 1970

Abstract

The influence of galvanic vestibular stimulation on the perception of rotation was investigated. The study was intended to lay the groundwork for future, more detailed study of the galvanic reaction. Of particular interest are possible clinical applications in the treatment of vertigo and the diagnosis of certain vestibular disorders. A set of experiments was designed to measure the gross effects of current intensity and point of application on a subject's

perception of rotation. An approximate threshold for the intensity effect was determined. Among points of application only polarity differences could be shown to be significant. A tentative linear relation between the bias in perception threshold and the intensity of current was found. The galvanic reaction of one vestibularly abnormal subject is also discussed.

Comparisons were made between galvanic stimulation and other common means of vestibular stimulation. Current mathematical models of vestibular function were reviewed and the extension of these models to include the galvanic reaction was examined.

Possible future directions for research in this area are also discussed.

4.5 Cumulative Nystagmus Measurement Program (MITNYS)

With the addition of some revisions and refinements the laboratory's data processing program for the PDP-8 to treat raw nystagmus data and eliminate fast phases to indicate cumulative eye position was completed by John Tole. The program has been useful not only in his work but for proposed research by P. Mirchandani on directional preponderance. We hope to use this on-line data reduction in a close-loop fashion in conjunction with our experiments on using visual stimuli to reduce vertigo and disorientation.

V. CYBERNETICS

5.1 Rapid On-Line Identification of Dynamic System Failures

During the preceeding year C. Ormsby has continued work on the problem of the adaptive control of a system which undergoes step changes in its dynamics. As reported previously, the method of system identification being studied is the method of modulating functions. A detailed report of this research is contained in his master's thesis, the abstract of which follows:

A Scheme for Rapid Adaptation To Sudden System Failures

by

Charles C. Ormsby
S.M. Thesis, June 1970

Abstract

This research is concerned with the problem of adaptive control of a system which undergoes step changes in its dynamics. The system chosen for this study was the roll dynamics of the Bell X-14A VTOL aircraft in hover, and the step changes in dynamics corresponded to failure of the systems rate and/or attitude stability augmentation. Since the post-failure dynamics are very unstable with the pre-failure controller, a scheme capable of rapid identification of the post-failure dynamics is necessary to stabilize the system.

The identification routine chosen for the adaptive control system is based on the method of modulating functions. An analysis of the effects of measurement noise on the identification of the system dynamics was carried out and the results were used to successfully implement the identification scheme. Computer simulations were used to test the performance of the identification routine with systems of different order, with varying levels of measurement noise and with varying identification intervals. The results indicate the feasibility of a reliable adaptive control system for the system studied.

The results of the study which analyzed the effects of measurement error on the capability of the identification scheme to correctly identify the system dynamics are summarized below.

The output of the identification scheme is a vector of parameters $\hat{\underline{\theta}}$ which are sufficient to specify the dynamics of the system being identified. This vector of parameters is determined by a matrix equation of the form: $\underline{A}\,\hat{\underline{\theta}} = \underline{b}$ where the entries in $\underline{A}$ and $\underline{b}$ depend on the measurements of system input and output. The analysis of the effects of measurement noise is divided into two parts. The first part investigates the statistics of the errors in the entries of $\underline{A}$ and $\underline{b}$ arising from measurement errors. The second part of the analysis is concerned with the transmission of these errors through matrix inversion ($\underline{A}^{-1}$) and subsequent multiplication by $\underline{b}$.

All of the entries in $\underline{A}$ (except the last column which is error free for the particular identification problem of this thesis) and $\underline{b}$ have additive error terms of the form:

$$N(T) \triangleq \int_0^T f(\frac{t}{T})\, n(t)dt$$

where $n(t)$ represents the measurement noise and $f(\frac{t}{T})$ are known functions. The major results of this part of the investigation can be expressed in a few equations. If the autocorrelation of $n(t)$, $\phi_{nn}(\tau)$ has correlation times long compared to T, then an upper bound on $\overline{N^2(T)}$ is given by:

$$\overline{N^2(T)} \leq T^2\, \phi_{nn}(0)\, \left[\int_0^1 f^2(r)dr\right]$$

If the correlation times of n(t) are small compared to T, then $\overline{N^2(T)}$ can be closely approximated by:

$$\overline{N^2(T)} \simeq \Phi\, T \left[\int_0^1 f^2(\eta)\, d\eta \right]$$

If the matrix $\underline{A}$ is decomposed into a noise free part $\underline{C}$ and error part $\underline{E}$ then we can write $\underline{A}$ as:

$$\underline{A} = \underline{C} + \underline{E}$$

In like manner $\underline{b}$ can be decomposed to yield:

$$\underline{b} = \underline{d} + \underline{f}$$

where $\underline{f}$ represents the error terms. The statistics of the entries in $\underline{E}$ and $\underline{f}$ were summarized above. Our estimate of $\underline{\theta}$ is given by:

$$\hat{\underline{\theta}} = \underline{A}^{-1}\, \underline{b} = (\underline{C} + \underline{E})^{-1}\, (\underline{d} + \underline{f})$$

whereas

$$\underline{\theta} = \underline{C}^{-1}\, \underline{d}$$

Neglecting terms that are second order in error we find that:

$$\underline{\Delta\theta} \triangleq \hat{\underline{\theta}} - \underline{\theta} \simeq \underline{C}^{-1}\, \underline{f} - \underline{C}^{-1}\, \underline{E}\, \underline{C}^{-1}\, \underline{d}$$

A measure of the error in the identification is:

$$\overline{\xi^2} = \overline{\underline{\Delta\theta}^T\, \underline{\Delta\theta}}$$

If we assume that the measurement errors on the input are independent and zero mean then:

$$\overline{\xi^2} \simeq \overline{\underline{f}^T\, \underline{C}^{-1^T}\, \underline{C}^{-1}\, \underline{f}} + \overline{\underline{d}^T\, \underline{C}^{-1^T}\, \underline{E}^T\, \underline{C}^{-1^T}\, \underline{C}^{-1}\, \underline{E}\, \underline{C}^{-1}\, \underline{d}}$$

If $\underline{A}$ is used to approximate $\underline{C}$, and $\underline{b}$ is used to approximate $\underline{d}$ then an estimate of $\overline{\xi^2}$ could be computed on line and would serve as a measure of the accuracy of the identification.

The results of this analysis of errors arising from measurement noise proved to be quite useful in implementing the identification scheme in the presence of noisy measurements.

5.2 Self-Organizing Control Systems and Applications to the Human Operator

P. B. Mirchandani has been working on the concept of hierarchical or self-organizing systems and their application to the man-machine problem. Whereas modern control theory goes from the specification of a desired performance index to the automatic generation of control laws, the next step in hierarchical control systems is the specification of a "generalized utility function". The utility defines a hypersurface in state space. The performance index at any time and, hence, the control is obtained from the criterion of maximizing utility. Mirchandani has explored notions of partitioning the utility function and using the concept of "independent attributes". The relative importance of various elements in maximizing utility is determined by the utility gradient. Thus the use of utility functions enables the designer in principle to specify what he thinks is important about the system performance at any given time and have the performance index determined automatically.

Applications of this theory to the human operator are of potentially great importance. Most of the existing human operator models consider the operator as a stationary system amd this makes

possible a linear representation of him. However, separate models are required for different control tasks and different inputs. These models do not take into account any fundamental invariancy of the human operator. Recent models of the human operator improved the state of the art by postulating the human operator as an optimal controller. Performance indices were obtained by trial and error until the model output matched the operator output. Separate performance indices were obtained for different systems. Still the invariancy of the human operator was not exploited to any great extent. Mirchandani postulates that the concept of self-organizing control systems would be very appropriate in modelling the human operator.

Let us consider the case of the human operator in a control task. Current adaptive (or learning) models attempt to capture an operator's behavior in terms of a stochastic process. An example of such a model is the Bayesian learning model. These models apply to situations in which the same choice is repeatedly presented and the outcome on each trial depends both on his response and on the stimulus presented. The theoretical problem is to discover what remains invariant from trial to trial, and therefore what constrains changes in the response probabilities.

In modelling human behavior in control tasks one must keep in mind that people exhibit at least three identifiable modes of behavior; adaptive (or learning), controlling and optimizing, and tracking "hypothesis testing". Most models do not include the third aspect of behavior and the first aspect has been included in very limited situations. By "hypothesis testing" we mean that the operator hypothesizes a model (usually a simple model of

plant and state) and acts accordingly. By the response of the system, he decides whether or not the hypothesis was true. If it is not true he switches to another hypothesis.

In the proposed theory we postulate that the human operator has a generalized utility function, with an a priori probability of where he is at on the hypersurface. We can accommodate the hypothesis testing mode by including the "hypothesis" as one of the coordinates in the utility space. The human operator would start at a certain state on this hypersurface and use that control which maximizes his utility over time. We postulate that the process of learning is the updating of the subjective probabilities as to where he is on the utility surface. This would simply imply that:

1. In a completely deterministic situation, with full knowledge of the system and the state of the system, a fully learned and highly motivated operator would give consistent responses.
2. In a situation where the plant is known completely, but the knowledge of the state of the system is stochastic, the fully learned and motivated operator would give stochastically consistent responses.
3. In a situation where the plant is unknown and the knowledge of the state of the system is stochastic, the operator will show learning behavior until the knowledge of the plant is known, and then the operator would give consistent results.
4. In a situation where the plant is a stochastic system the operator will show learning behavior until the

knowledge of the probabilistic behavior of the plant is nearly equivalent to the real behavior, and then the operator would give stochastically consistent results.

If the task of the human operator is always the same, for example, to bring the state of the system to null position, then we could note that the utility function (as a function of state only) is always the same regardless of the type of plant. We may thus be able to work with one less coordinate, namely the coordinate of hypothesis, and include elsewhere in the system. Particularly for the human operator the hypothesis would take the place of an identificator in the control system.

5.3 Symmetrical Properties and Learning Theories

Recognizing that the manual control problems of practical interest are becoming increasingly ones of predicting human learning and decision making and complex choice situations rather than simple servomechanism-like control behavior, we have attempted to extend our research into the realm of theories of problem solving. Dr. Alan Natapoff has joined our group and pursued his interests in this area.

Two kinds of problems are being pursued that relate to strategic principles underlying abstract choice and problem-solving in evolving systems.

First, we are investigating the way symmetry enters the description (and can simplify the analysis) of simple choice experiments. There is a great deal of data available (largely on pigeon behavior) from experimenters in the area. With the help of Professor Richard Herrnstein (Harvard, Department of Psychology),

the approaches suggested by the application of group theory are being explored.

Some of the work is purely formal, developing group-theoretic tools to match the form of the experimental paradigms. One set of results is to be published this fall in the Journal of Mathematical Psychology.

Another phase of that work seeks to exploit those results to find simple strategic principles that characterize the choice behavior observed as among the many possibilities consistent with symmetry. Since paired symmetric optic or auditory nerve responses (as well as behavior choice responses) fall under the formal category being investigated, the results might have a wide set of applications, both theoretical and practical. In long-term, one might hope to learn something of the properties of choice systems that enhance their survival, and of the underlying optimal principles. The results might, as an application, be illuminating for the design of simple artificial intelligence systems.

The second research area is that of abstract problem-solving in humans. We are trying to exploit the presumed slow rate of evolutionary change in higher brain as a constraint on the mechanisms available to explain the observed human faculties.

Starting from a particular hypothesis (Perspectives in Biology and Medicine, 10, 445-461, [1967]), we have been developing a set of experiments to test the usefulness of the approach. These experiments, using the teaching of long division as a probe, have been tried with small statistics on a sample of students in the Brookline, Massachusetts public schools. The results in these pilot studies were consistent with theoretical predictions and a

larger experimental group is being prepared to provide detailed data. A long term hope of this research is some clarification of the relation between sensory processes and abstract problem-solving, and of the mathematical character of the mechanisms involved.

VI. COMPUTER DEVELOPMENT AND LABORATORY FACILITIES

6.1 Hybrid Computer Operating System

Our hybrid computer system continues to be improved both in hardware and software. Four additional channels of D-A conversion were installed by C. Oman. The operating system of the PDP-8 computer was modified to make full use of the capabilities of the DEC-tape data storage system. These modifications were described in a paper by N. Van Houtte and C. Oman presented at the DECUS Spring Symposium at Atlantic City, New Jersey, May 1970. The abstract of that paper follows.

The M.I.T. Man Vehicle Laboratory PDP-8 Programming System

by

Noel A.J. Van Houtte and Charles M. Oman

Abstract

During the past three years, users of the DECUS 8-64 DECtape programming system at the M.I.T. Man Vehicle Laboratory have more fully debugged the routines, and made some modifications which make them more flexible. The 8-64 system is presently the only all DECtape system generally available for use with the 552 DECtape control. Major improvements include: modifications to the symbolic editor and PAL III input and output routines allowing access to a number of tape drives, complete protection for system files, and a feature allowing optional complete listing of the tape directory. Additional programming notes are also included on changes to the PAL III and FORTRAN II instruction sets, and on operations involving series and factorial computations using Digital 8-10S CALCULATOR.

Van Houtte and Oman also presented a paper at that symposium on our display generating techniques, the abstract of which follows.

Hybrid Computer Display Techniques Involving a PDP-8

by

Noel A.J. Van Houtte and Charles M. Oman

Abstract

The hybrid facility in the M.I.T. Man Vehicle Laboratory, consisting of a PDP-8 and a GPS-290T, has been used to develop a linear perspective image of a three-dimensional object.

The presentation of the image on a large screen CRT tube looks like the scene an aircraft pilot would see if he were looking out the cockpit window.

The role of the digital computer is to keep track of the coordinates of reference points in inertial space, taking into account the motion of the simulated aircraft, and to compute the information received for the display.

The analog part of the facility takes this display information by an interrupt request and draws the picture.

Initial development of the display was done using a cube as the displayed object. The system has also been used to produce a contact analog display for a VTOL aircraft landing under category III conditions.

6.2 Integration of Link GAT-1 in the Laboratory

The Link GAT-1 has been used for our display research and is expected to have increasing use both as a disorientation device and for measurements of pilot workload. Bypassing the internal computer to run the device as a general purpose moving base simulator through our hybrid computer is, however, not a trivial task. Thus far the necessary instrumentation has been implemented to enable the attitude for the GAT-1 trainer to be computed by the hybrid computer. Plans for the fall of 1970 are to completely bypass the internal Link computer. This work is being supervised by John Hatfield.

VII. MEDICAL APPLICATIONS

7.1 Glaucoma Research

As a result of our continuing interest in the eye and its control systems, inculding the regulation of intraocular pressure, we have embarked on a new research project in the area of glaucoma. In collaboration with Dr. Richard Brubaker (currently at the National Institutes of Health; after July 1970, at the Mayo Clinic) we are developing instrumentation to measure the degree of stretching of the sclera during tonography. Minute stretching of the sclera could account for apparently large changes in measured facility or resistance to outflow of fluid from the eye. The measurement is expected to be difficult. The instrumentation is being developed with a model eye at M.I.T. using a laser interferometer system with corner cube reflectors mounted on the front and rear surfaces of the eye. The actual in vivo measurement in monkeys will be performed using this instrument by Dr. Brubaker at Mayo Clinic. The research is currently sponsored by a seed research grant from the Sarah Reed Eye Foundation. The work is being done chiefly by Mr. L. Chin with the additional supervision of Professor S. Ezekiel of the Department of Aeronautics and Astronautics.

7.2 Clinical Applications of Synchronized Photography and Hybrid Computer Displays

A set of programs and film synchronization techniques has been developed and tested by Mrs. H. L. Galiana to provide the orthopedic surgeon with accurate information on limb movements and associated muscular activities. The summary of her report on this work follows:

Clinical Applications of Synchronized Photography and Hybrid Computer Displays

by

H. L. Galiana

The application of hybrid computer displays to clinical studies has been investigated. Specifically, in the study of pathological movements, the orthopedic surgeon requires accurate synchronized information on limb movements and associated muscular activities (electromyograms, EMG's). Such data can then be used by the physician to help in prescribing any appropriate surgery or physio-therapy. The same approach can further be applied to study the patient's subsequent progress.

To date, most techniques to obtain the desired information have involved either recording EMG's on the sound track of a movie film or using split-frame photography to record on film simultaneously the subject and the EMG traces from a CRT screen. The subject is usually instrumented with surface electrodes (or other) connected via an overhead boom to preamplifiers and a CRT-camera system on a trolley. However, the resulting film is usually unsuitable for single frame viewing, since only a few cycles of EMG can be observed on each frame.

This report presents a possible alternative using a hybrid computer-controlled CRT display, which could be applied to any instances where synchronous visual and bioelectric and/or physical information is required. The overhead boom is replaced with telemetry, freeing the subject for more complex movements. Furthermcre, the recorded data is subsequently manipulated on a hybrid computer (PDP-8/GPS-290T) to produce any desired display on a CRT screen. The films of subject and CRT display are processed to produce a movie film of synchronized full-frame superimposed movements and data. Increased versatility is obtained at the cost of increased film and data processing.

Such an approach would be valuable not only in clinical diagnosis but also in basic research studies. The computer display can be made to represent forces, torques, temperature, EMG's, etc., in any desired form or combination. The complexity of the display is only limited by the results of a trade-off between the desired display frame rate and the cycle time of necessary calculations.

VIII. LIFE SUPPORT IN UNUSUAL ENVIRONMENTS

8.1 New Areas of Biotechnology

We have continued our study of a number of life support projects under a separate grant (NGR 22-009-312). The reviews and evaluations of promising areas of biotechnology appropriate for future university research projects are contained in a series of summary reports issued under that grant. The work has been under the general direction of Professor Young and coordinated by Mrs. H. L. Galiana and Mr. J. Hatfield. Those areas which have received extensive study this past year are atmospheres for space and oxygen storage (Professor R. Reid, Department of Chemical Engineering), water recovery (J. Tole), contaminant monitoring (H. L. Galiana), temperature control for EVA (A. Ephrath), EVA attitude control (L. Von Renner), and space power systems (L. Chin).

8.2 Summer Course in Aerospace and Undersea Medicine

In conjunction with some of our work in this area, we organized a summer course in Aerospace and Undersea Medicine in collaboration with Dr. Sherman Vinograd of NASA Headquarters. The course was received enthusiastically when it was given in August, 1969.

IX. STAFF

The Man-Vehicle Laboratory made several significant additions to its staff in the academic year of 1969-70, representing both an increase in breadth of its studies and engineering depth. The key to the laboratory research continues to be its sixteen graduate students and approximately four undergraduates participating in its activities. Professors Young and Meiry continued their active role in research supervision and Professor Li returned from sabbatical leave to guide our research, especially into some of the newer areas of displays. Dr. Renwick Curry joined our laboratory as Assistant Professor of Aeronautics and Astronautics from the faculty of Electrical Engineering at Cornell University. Professor Curry is a valuable addition to our group with his background in identification techniques and interest in biological and psychological control problems. He has taken leadership in the area of pilot warning indicators and displays. Dr. Alfred Weiss, a neurologist at the Harvard Medical School and Massachusetts Eye and Ear Infirmary, joined our laboratory as a part time research associate, and has contributed valuable medical inputs on several neuromuscular and vestibular areas. Dr. Alan Natapoff, a physicist with interest in biomathematics, also joined our group as a research associate and leads our exploration of theoretical problems in learning and decision making. Mr. John Hatfield joined the laboratory in the spring as a staff engineer and has taken over much of the hardware development phases for the pilot warning indicator display work and integration of our link simulator to the laboratory computer system. Mr. Hatfield, who has extensive systems

experience, most recently worked on the VTOL program at NASA/ERC. Mr. Lang Chin joined the laboratory as a DSR Staff member and is working principally on the glaucoma research project and making contributions to the life support program. Mrs. H. L. Galiana, who had contributed so heavily to the life support programs and the EMG display project, left the laboratory for personal reasons in March, 1970. Dr. Anil Phatak, who was a research associate at our laboratory since the fall of 1968, left in September, 1969 to join the faculty of the University of Southern California as an Assistant Professor of Electrical Engineering, where he is continuing his research in manual control and biological control systems. We have also been fortunate to have had the excellent services of a new technician, Mr. Richard Carr, and two excellent secretaries, Mrs. Annette Markowitz and Mrs. Carol Hartman.

X. PUBLICATIONS AND THESES OF THE MAN-VEHICLE LABORATORY, 1969-70

Young, L. R., "On Adaptive Manual Control," Ergonomics, Vol. 12, No. 4, July, 1969, 635-674.

Curry, R. E., "A Separation for Non-Linear Measurements," IEEE Transactions on Automatic Control, Vol. 14, No. 5, October, 1969; Also presented at the 1969 JACC Conference, Boulder, Colorado, August, 1969.

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Curry, R. E., "A New Algorithm for Suboptimal Stochastic Control," IEEE Transactions on Automatic Control, Vol. 14, No. 5, October, 1969, 533-536.

Young, L. R., and Oman, C. M., "A Model for Vestibular Adaptation," Aerospace Medicine, Vol. 40, No. 10, October, 1969, 1076-1080.

Mathur, Dilip K., "Organization of Information Processes," S.M. Thesis, M.I.T., January, 1970.

Curry, R. E., and Vander Velde, W. E., "An Extended Criterion for Statistical Linearization," IEEE Transactions on Automatic Control, Vol. 15, No. 1, February, 1970, 106-108.

Curry, R. E., Vander Velde, W. E., and Potter, J. E., "Non-Linear Estimation with Quantized Measurements: PCM, Predictive Quantization, and Data Compression," IEEE Transactions on Information Theory, Vol. 16, No. 2, March, 1970, 152-161.

Curry, R. E., "Research on Collision Warning Displays," presented at Sixth Annual Conference on Manual Control, Wright-Patterson AFB, April, 1970.

Nashner, Lewis M., and Meiry, Jacob L., "Sensory Feedback in Human Posture Control," presented at the Sixth Annual Conference on Manual Control, Air Force Institute of Technology, Dayton, Ohio, April, 1970.

Van Houtte, Noel A. J., "A Perspective Glideslope Indicating System," presented at the Sixth Annual Conference on Manual Control, Dayton, Ohio, April, 1970.

Young, L. R., and Oman, C. M., "Modelling Adaptation on Human Semicircular Canal Response to Rotation," in Transactions of the New York Academy of Sciences, April, 1970 (in press).

Curry, R. E., "Estimation and Control with Quantized Measurements," presented at MSL-NASA Symposium, Cambridge, Mass., May, 1970.

Reid, Robert C., "University Role in Astronaut Life Support Systems: Atmospheres," NASA Contractor Report 1552, May, 1970.

Van Houtte, Noel A. J., and Oman, C. M., "Hybrid Computer Display Techniques Involving a PDP-8," presented at DECUS Spring Symposium, Atlantic City, May, 1970.

Van Houtte, Noel A. J., and Oman, C. M., "The M.I.T. Man-Vehicle Laboratory PDP-8 Programming System," presented at DECUS Spring Symposium, Atlantic City, May, 1970.

Chang, Eric, "Evaluation of Elements in a Contact Analog Display," S.M. Thesis, M.I.T., June, 1970.

Nashner, Lewis M., "Sensory Feedback in Human Posture Control," Sc.D. Thesis, M.I.T., June, 1970.

Ormsby, Charles C., "A Scheme for Rapid Adaptation to Sudden System Failures," S.M. Thesis, M.I.T., June, 1970.

Tole, John, "Galvanic Stimulation and the Perception of Rotation," S.M. Thesis, M.I.T., June, 1970.

Van Houtte, Noel A. J., "Display Instrumentation for V/STOL Aircraft in Landing," Sc.D. Thesis, M.I.T., June, 1970.

Von Renner, Lonnie C., "Extravehicular Attitude Control by Use of Head Motion," S.M. Thesis, M.I.T., June, 1970.

Galiana, H. L., "University Role in Astronaut Life Support Systems: Monitoring Atmospheric Contaminants," NASA Contractor Report (in press).

Tole, John R., "University Role in Astronaut Life Support Systems: Water Recovery Systems," NASA Contractor Report (in press).

Von Renner, Lonnie C., "University Role in Astronaut Life Support Systems: Extravehicular Guidance and Stabilization in Space," NASA Contractor Report (in press).

Young, L. R., "Pursuit Eye Tracking Movements," in The Control of Eye Movements, Bach-y-Rita and Collins, ed., Academic Press, New York (in press).

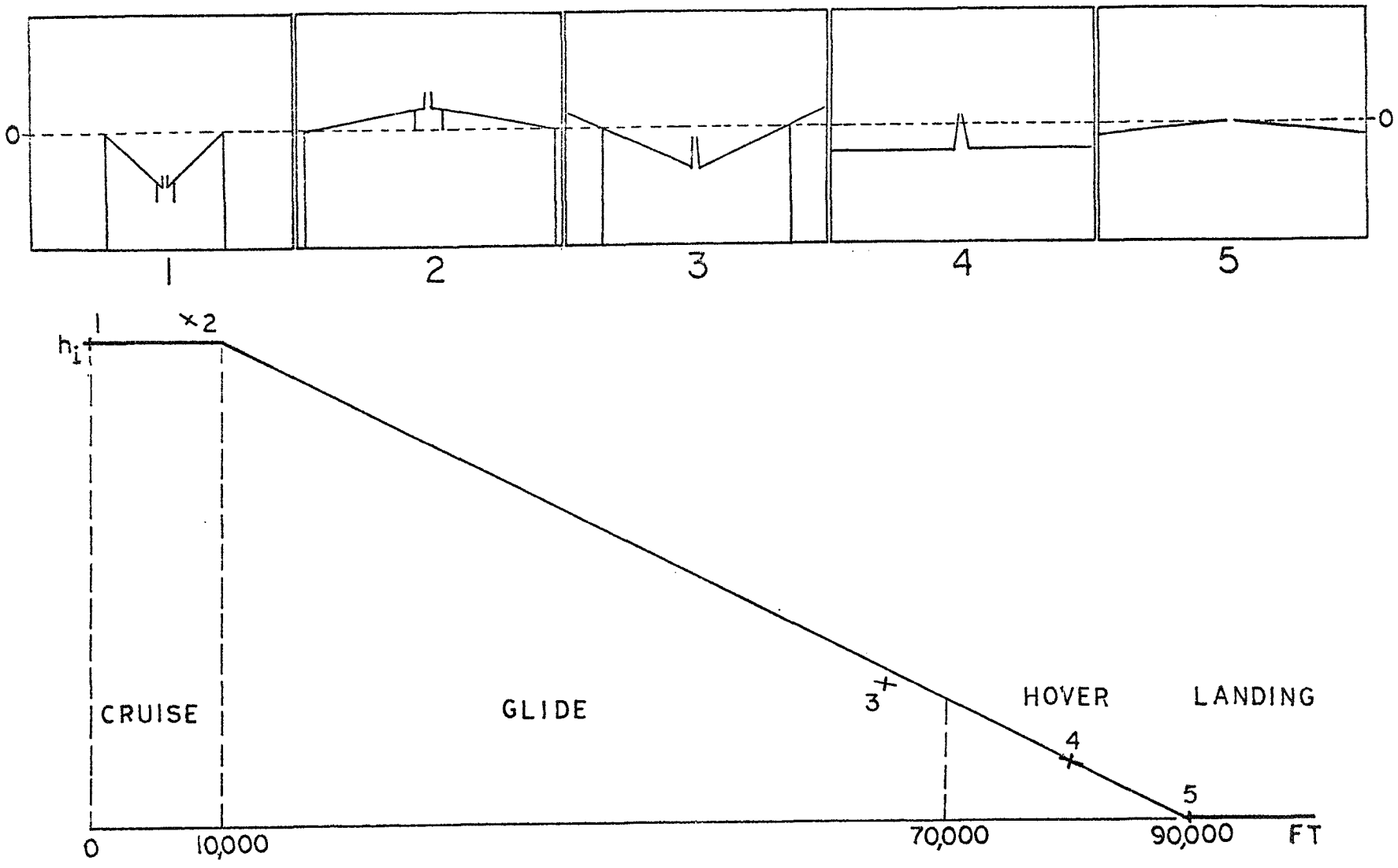


Figure 1. The different views as seen from the indicated positions. (It is assumed that one is on the localizer beam.)

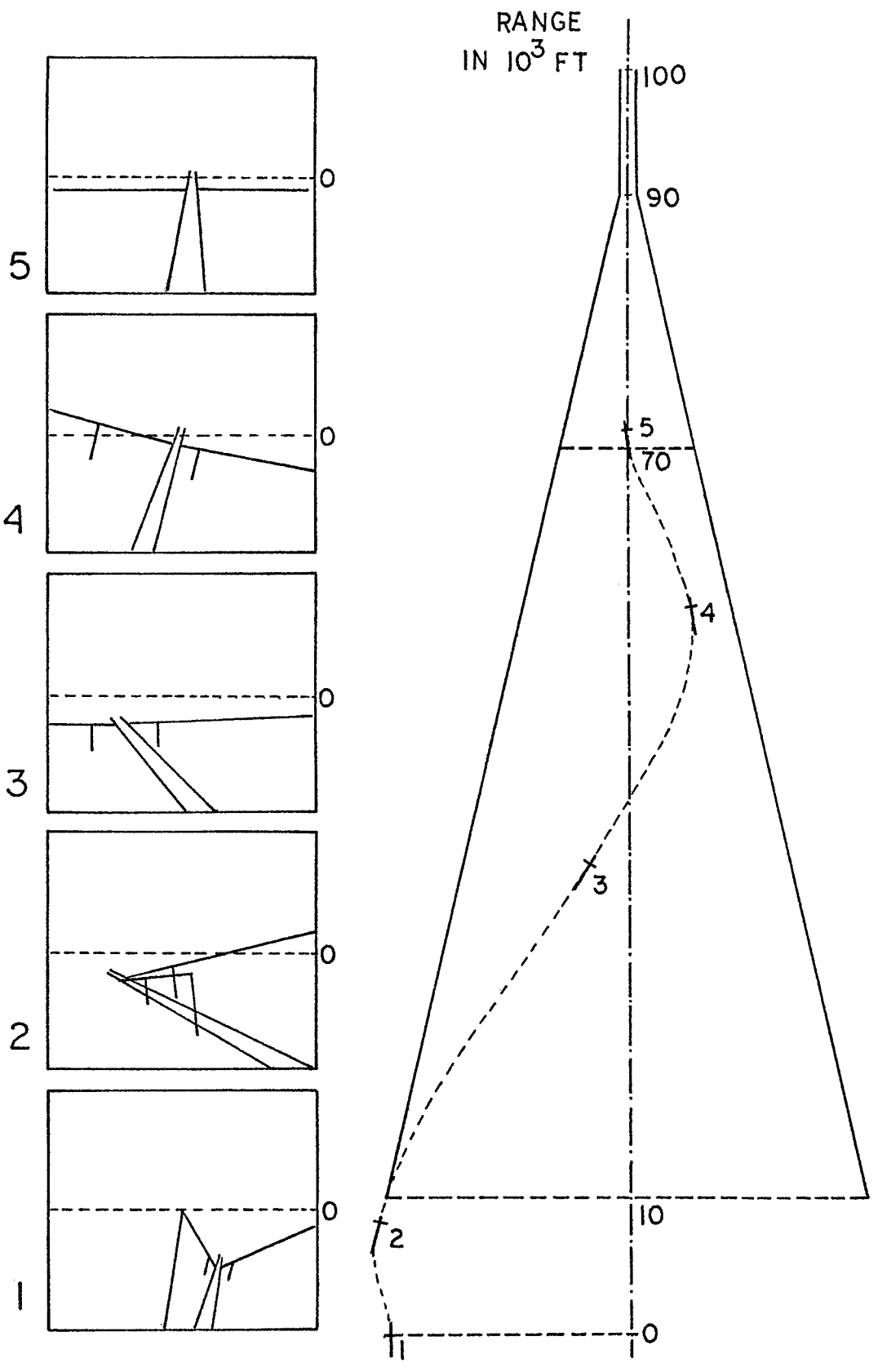


Figure 2. The perspective display scheme two, illustrating heading and roll changes.

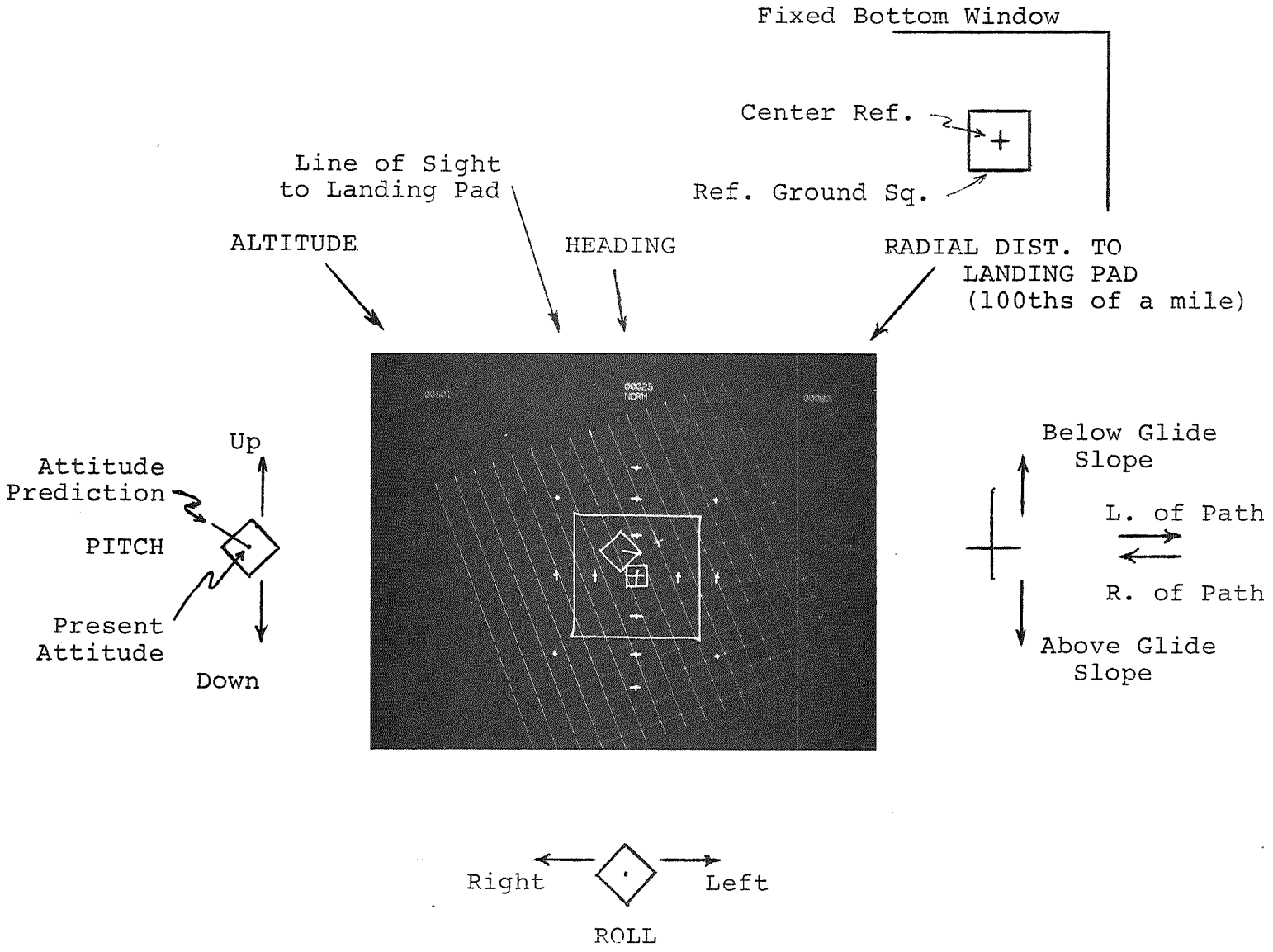
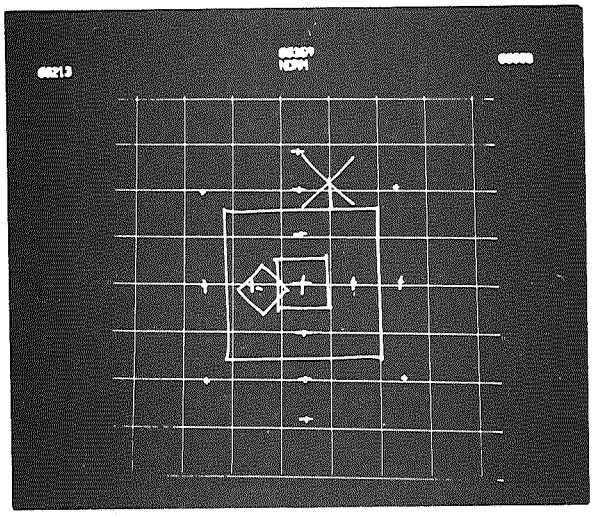


Figure 3. Integrated Bottom Window Display



1. Approaching to left of landing pad (0.08 mi. away).
2. Banked right (about 10°), zero pitch.
3. Altitude: 213 ft.
4. Heading: 359°

Figure 4. Integrated Bottom Window Display

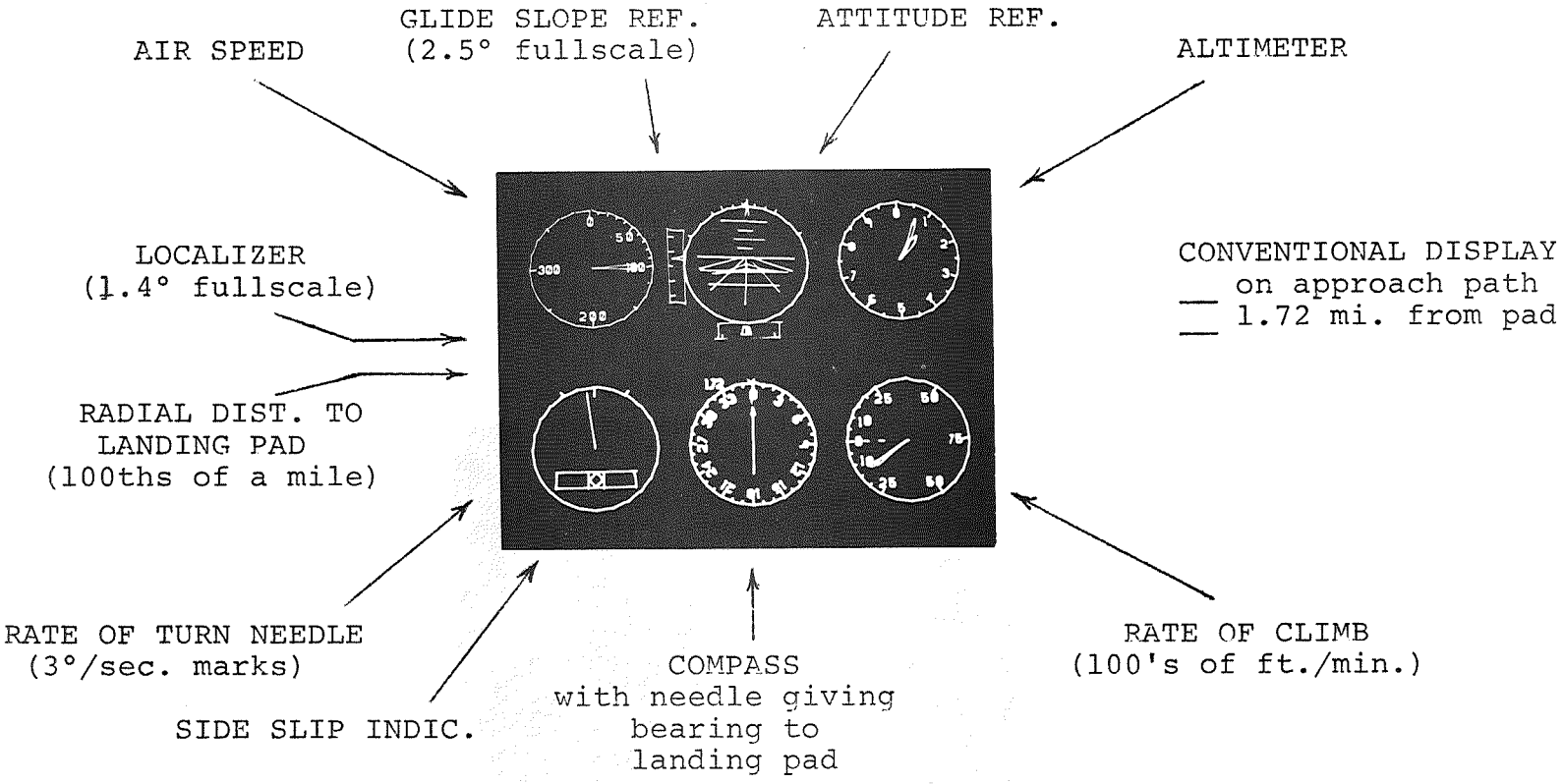
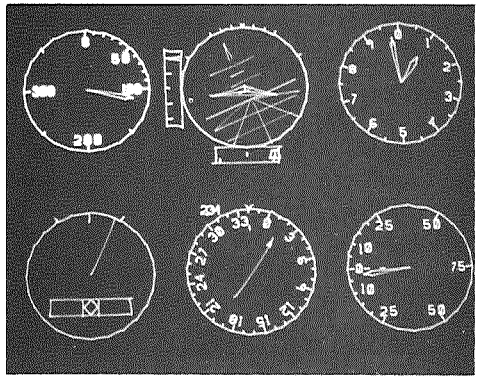


Figure 5. Simulated Conventional Display System

CONVENTIONAL DISPLAY



1. Presently left of approach path and below glide slope.
2. Nearly 10° pitch up.
3. Banking right.
4. 2.34 mi. from landing pad.

Figure 6. Simulated Conventional Display System